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(71) Applicant(s)
Cranfield University
(Incorporated in the United Kingdom)
Institute of Bioscience and Technology, CRANFIELD, Beds, MK43 0AL, United Kingdom

(72) Inventor(s)
Sheikh Rafi Ahmad
Edwin Billiet
Carsten Rogge

(74) Agent and/or Address for Service
Haseltine Lake & Co
Imperial House, 15-19 Kingsway, LONDON, WC2B 6UD, United Kingdom

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US 4567370 A

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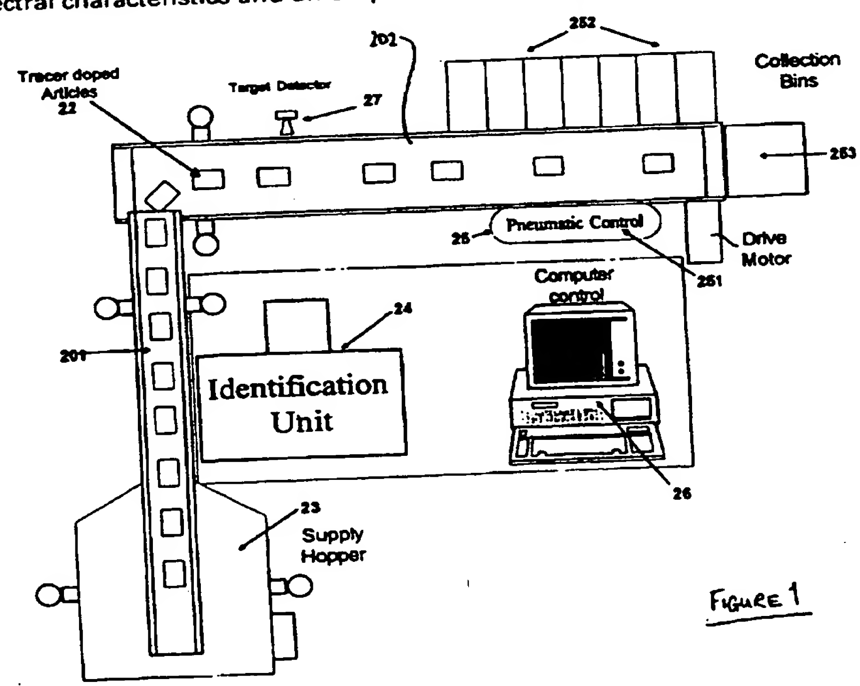
ONLINE: WPI

(54) Abstract Title
Identifying plastics for recycling

(57) In a system to identify a substance eg a type of plastic in a recycling system, a sample 22 is illuminated with ultraviolet light 24 and the induced fluorescence is detected. An image relating to the intensity of the detected fluorescence is stored and compared to reference data to allow the substance to be identified. The plastic may be impregnated with a plurality of fluorescent tracers to produce a characteristic fluorescence for that plastic type.

Also disclosed (figure 7) is a filter comprising a plurality of mirrors arranged on a circular frame which mirrors are transparent to particular wavelengths and reflective to others to create a beam having a predetermined spectral characteristics and an output direction that is rotated with respect to the input direction.



Aid on Step 3

Figure 1

GB 2 330 409 A

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

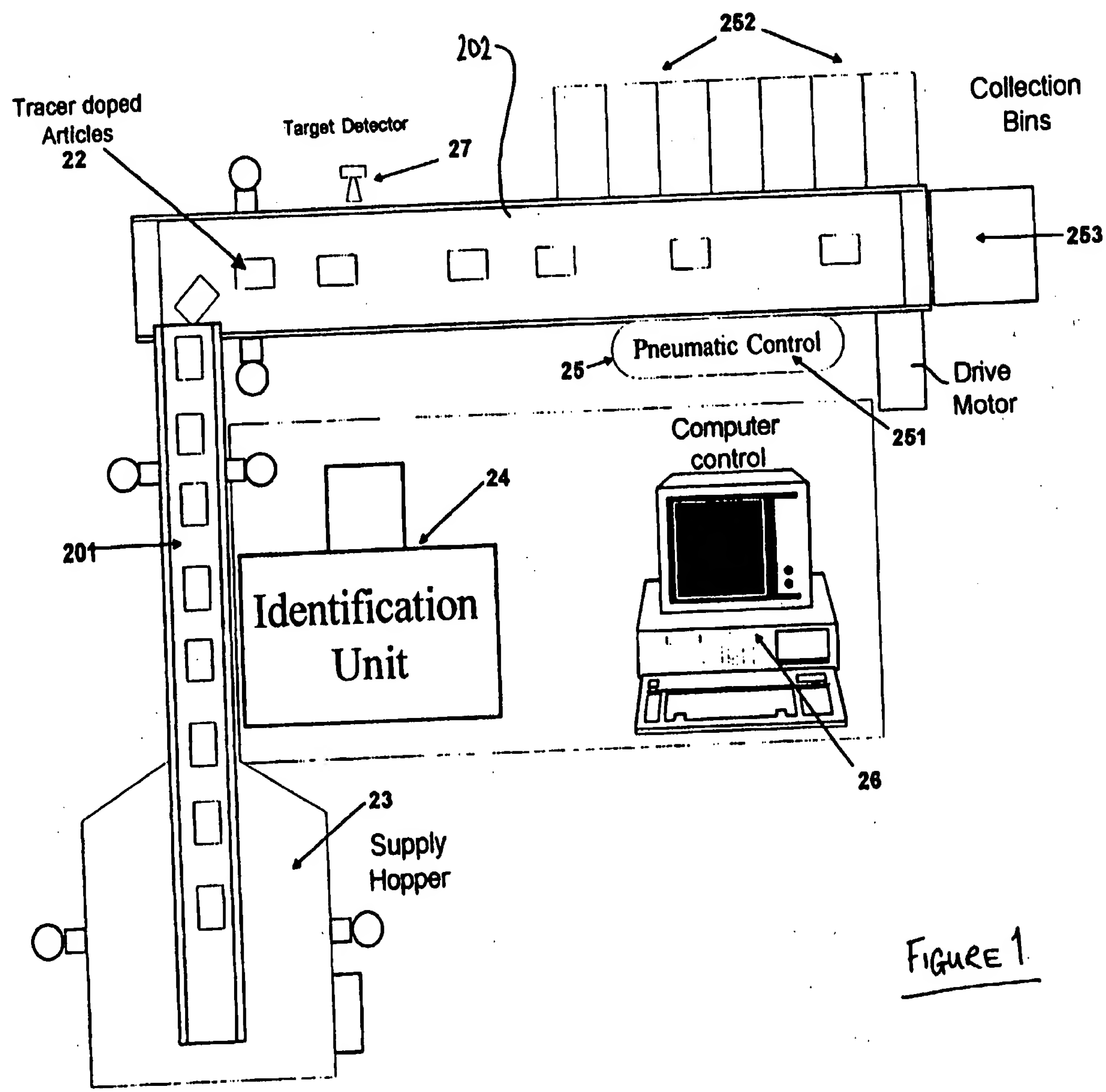

Tracer doped
Articles
22
Target Detector
27
202
252
Collection
Bins
253
Pneumatic Control
25
251
Drive
Motor
Computer
control
201
24
Identification
Unit
26
23
Supply
Hopper

FIGURE 1

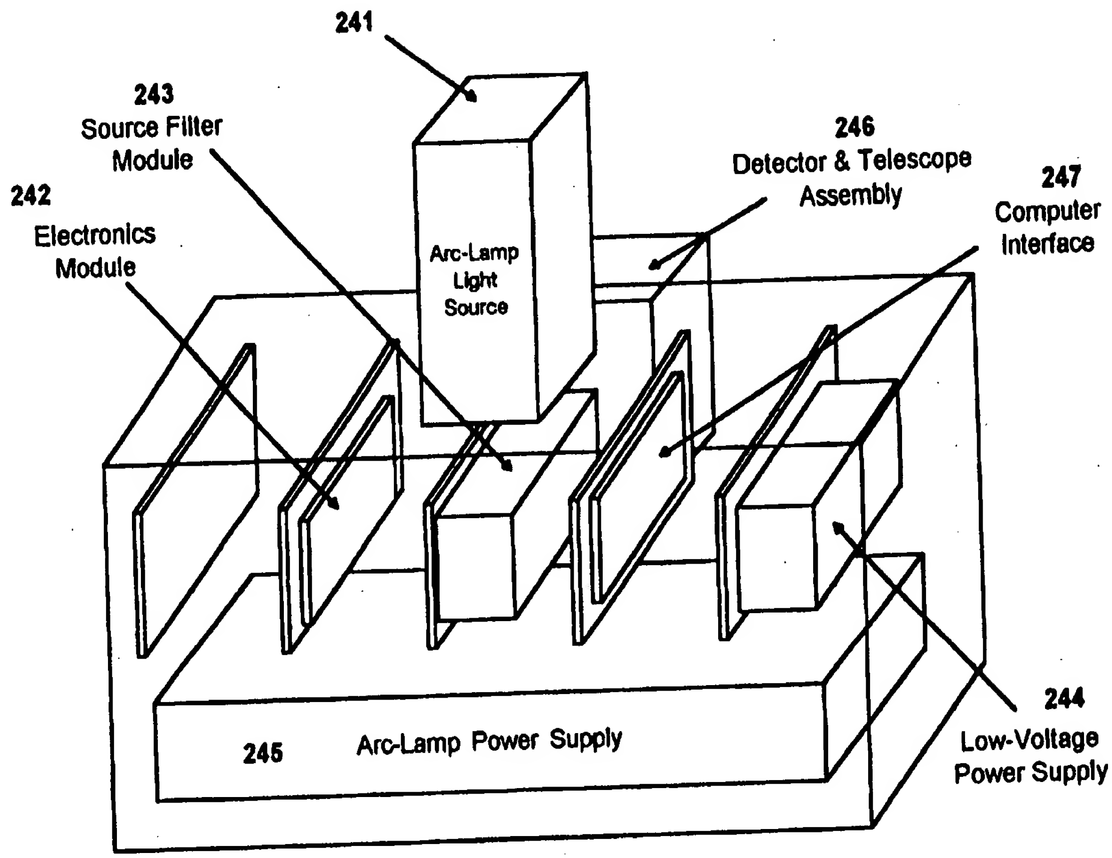

241
243
Source Filter
Module
242
Electronics
Module
Arc-Lamp
Light
Source
246
Detector & Telescope
Assembly
247
Computer
Interface
245
Arc-Lamp Power Supply
244
Low-Voltage
Power Supply

FIGURE 2

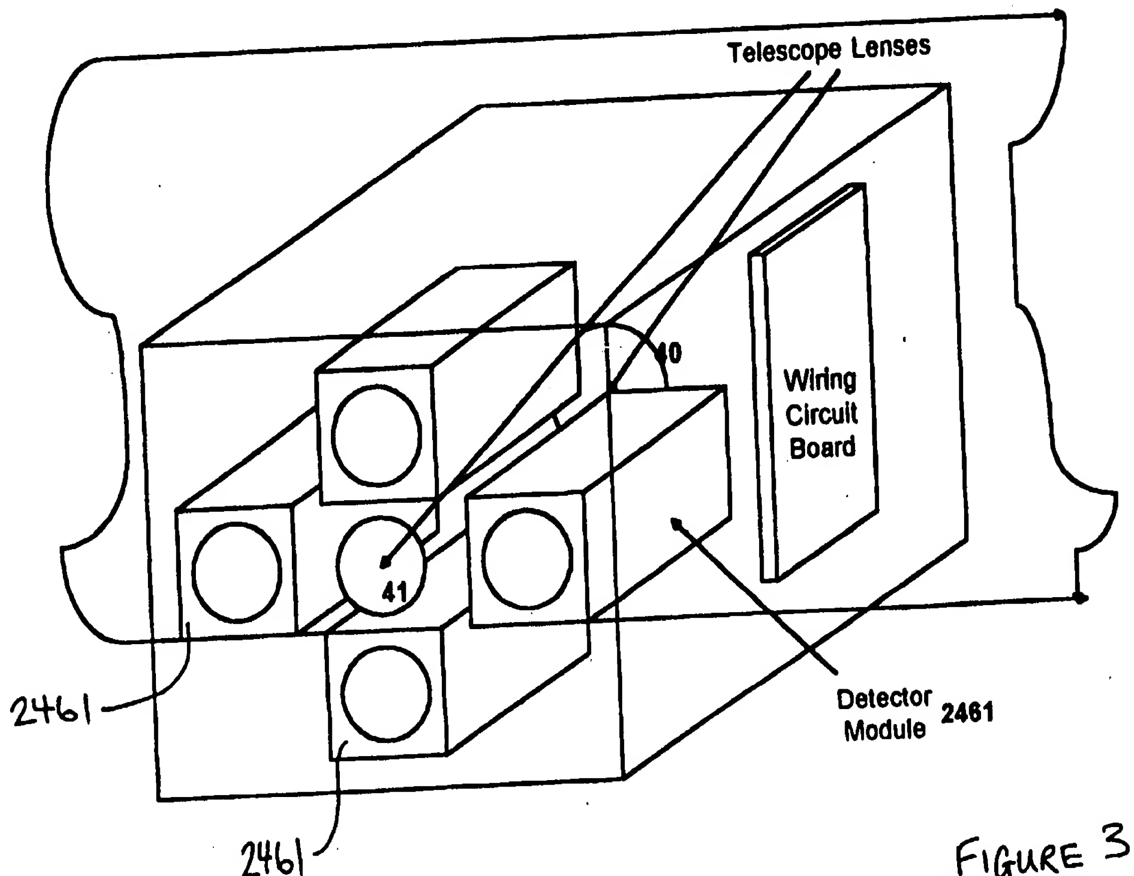

Telescope Lenses
40
Wiring
Circuit
Board
41
2461
2461
Detector
Module
2461

FIGURE 3

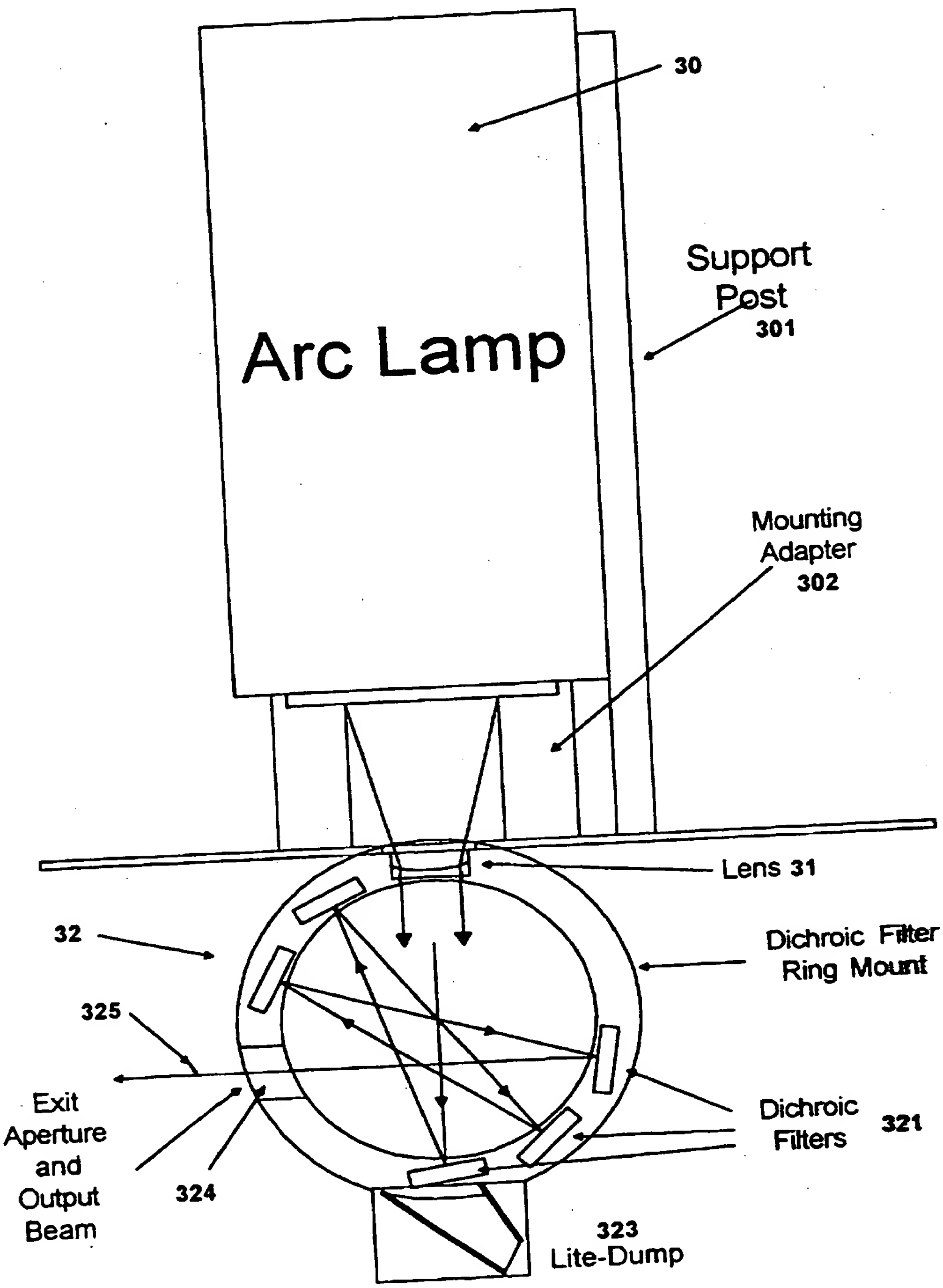

30
Arc Lamp
Support Post 301
Mounting Adapter 302
Lens 31
32
Dichroic Filter Ring Mount
325
Exit Aperture and Output Beam
324
Dichroic Filters 321
323 Lite-Dump

FIGURE 4

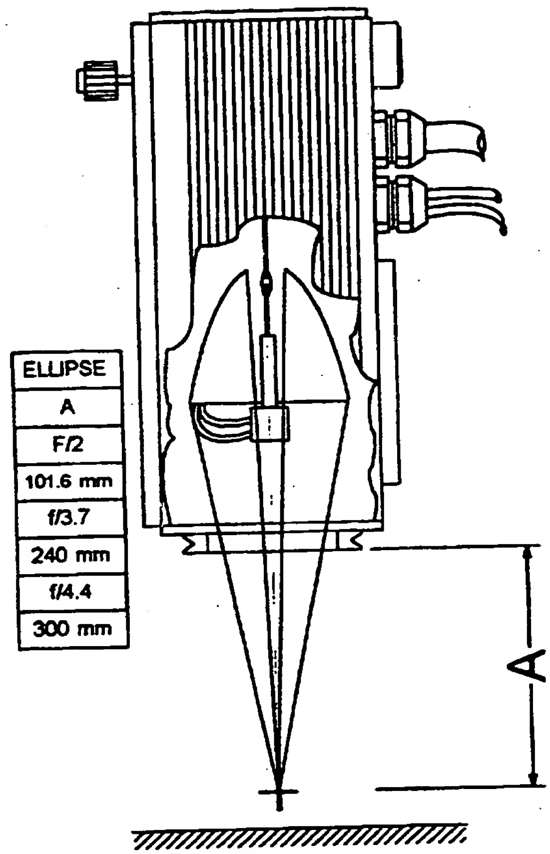


FIGURE 5

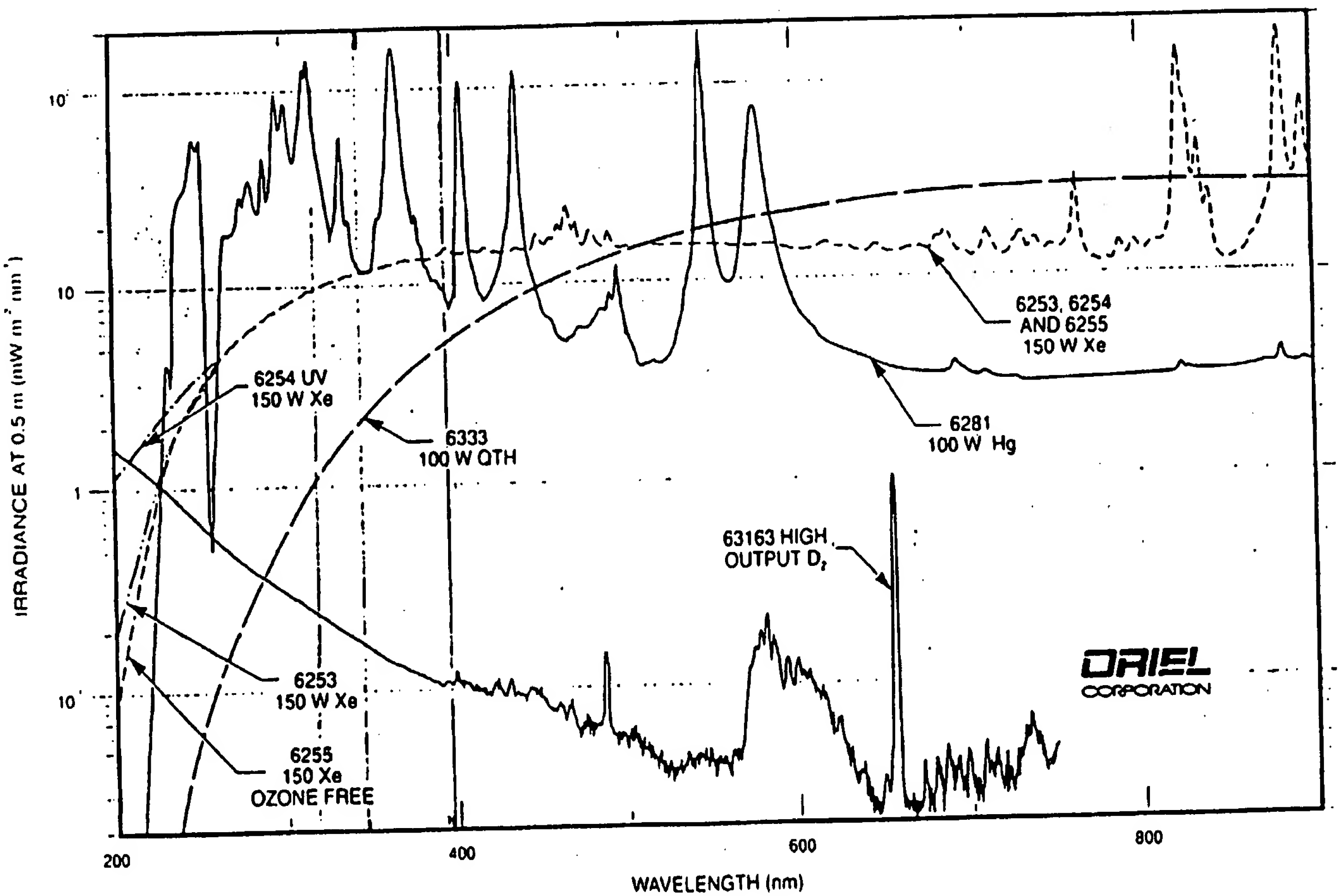

IRRADIANCE AT 0.5 m (mW m⁻² nm⁻¹)
10
10
1
10
200
400
600
800
WAVELENGTH (nm)
6254 UV
150 W Xe
6333
100 W QTH
6253, 6254
AND 6255
150 W Xe
6281
100 W Hg
63163 HIGH
OUTPUT D₂
6253
150 W Xe
6255
150 Xe
OZONE FREE
ORIEL
CORPORATION

FIGURE 6

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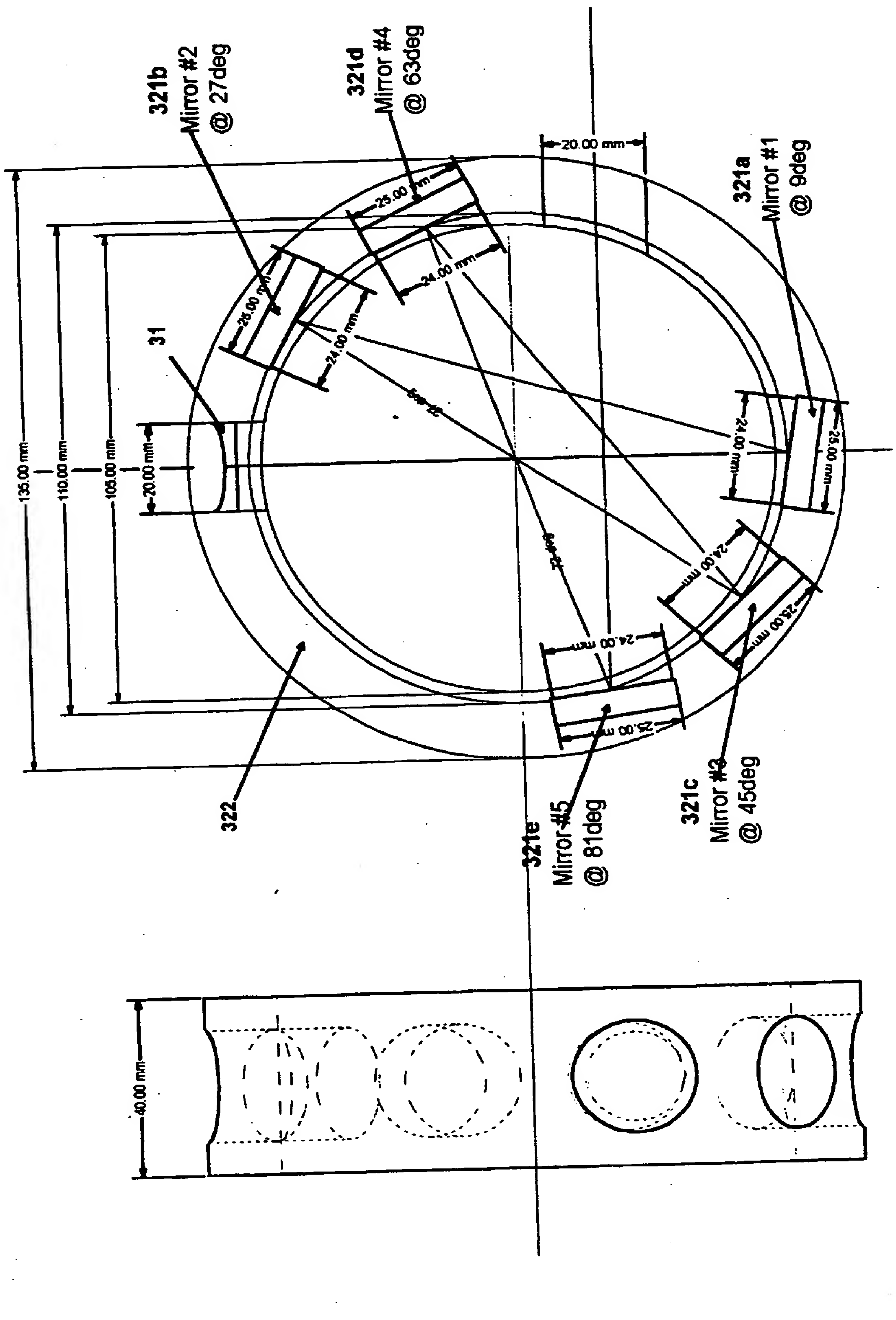
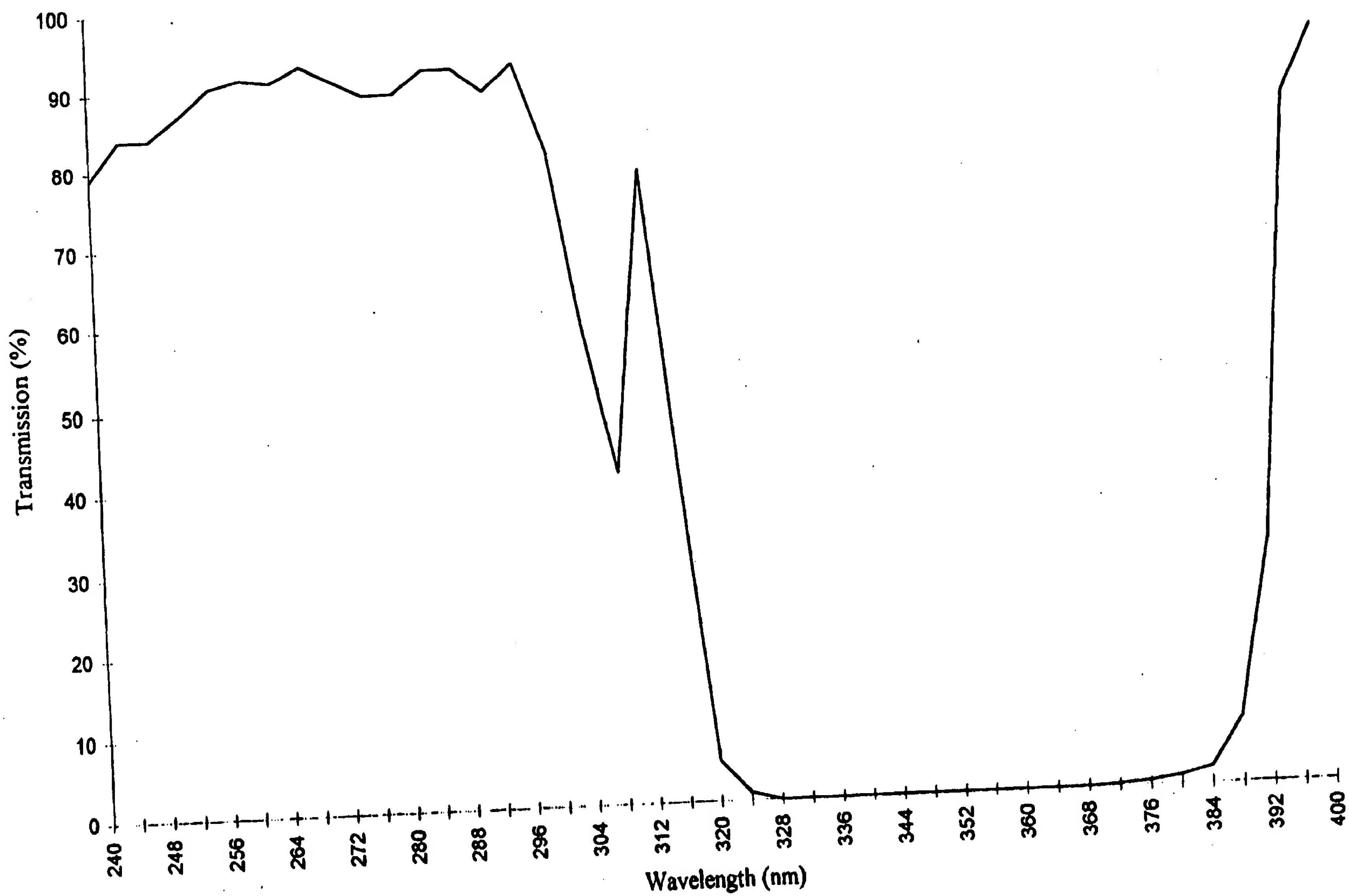


321b
Mirror #2
@ 27deg
321d
Mirror #4
@ 63deg
321a
Mirror #1
@ 9deg
31
322
321e
Mirror #5
@ 81deg
321c
Mirror #3
@ 45deg
20.00 mm
25.00 mm
24.00 mm
135.00 mm
110.00 mm
105.00 mm
40.00 mm

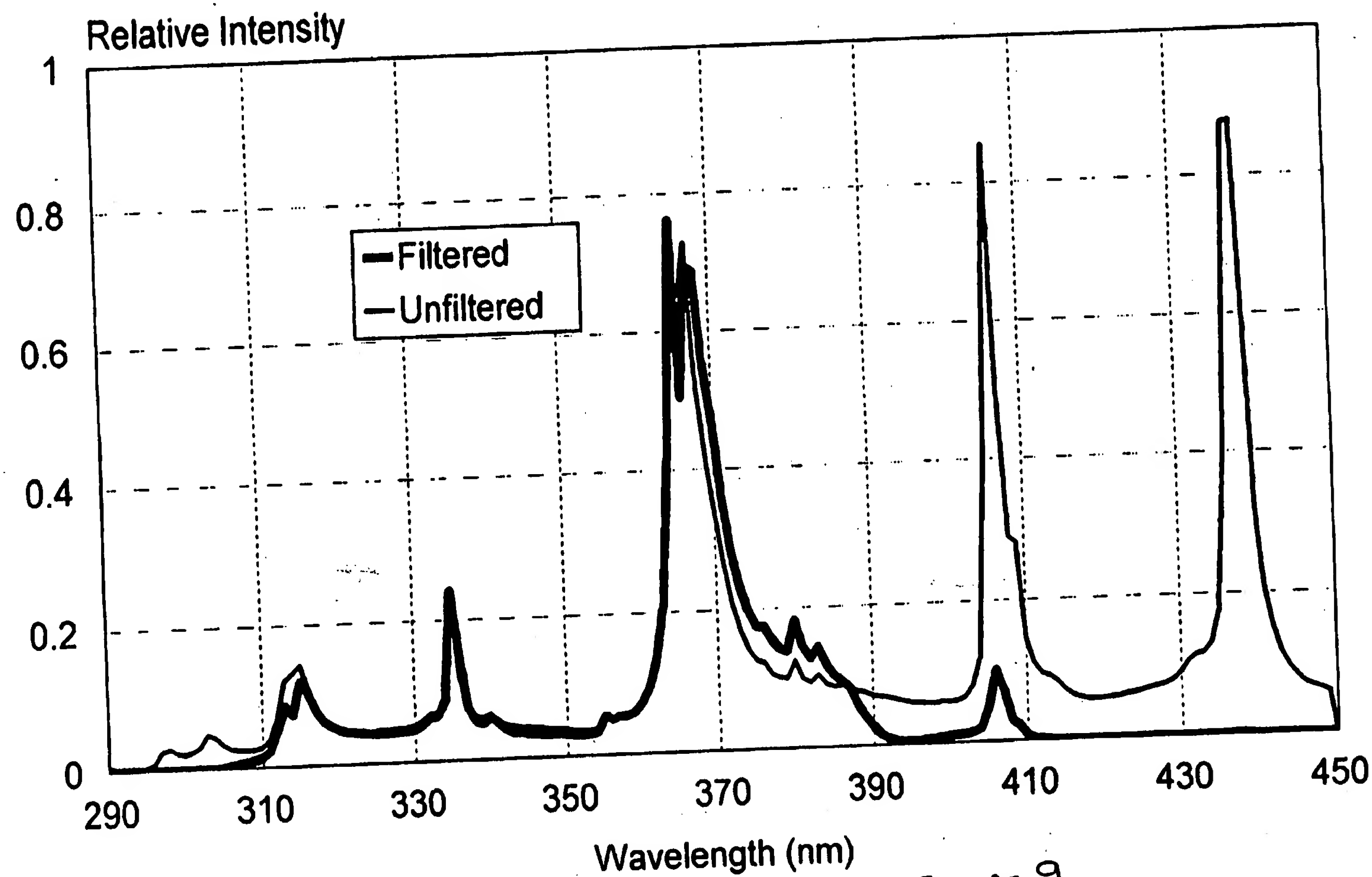
FIGURE 7

FIGURE 8



Transmission (%)
100
90
80
70
60
50
40
30
20
10
0
240
248
256
264
272
280
288
296
304
312
320
328
336
344
352
360
368
376
384
392
400
Wavelength (nm)

8/15



Relative Intensity
1
0.8
0.6
0.4
0.2
0
290
310
330
350
370
390
410
430
450
Wavelength (nm)
Filtered
Unfiltered

FIGURE 9

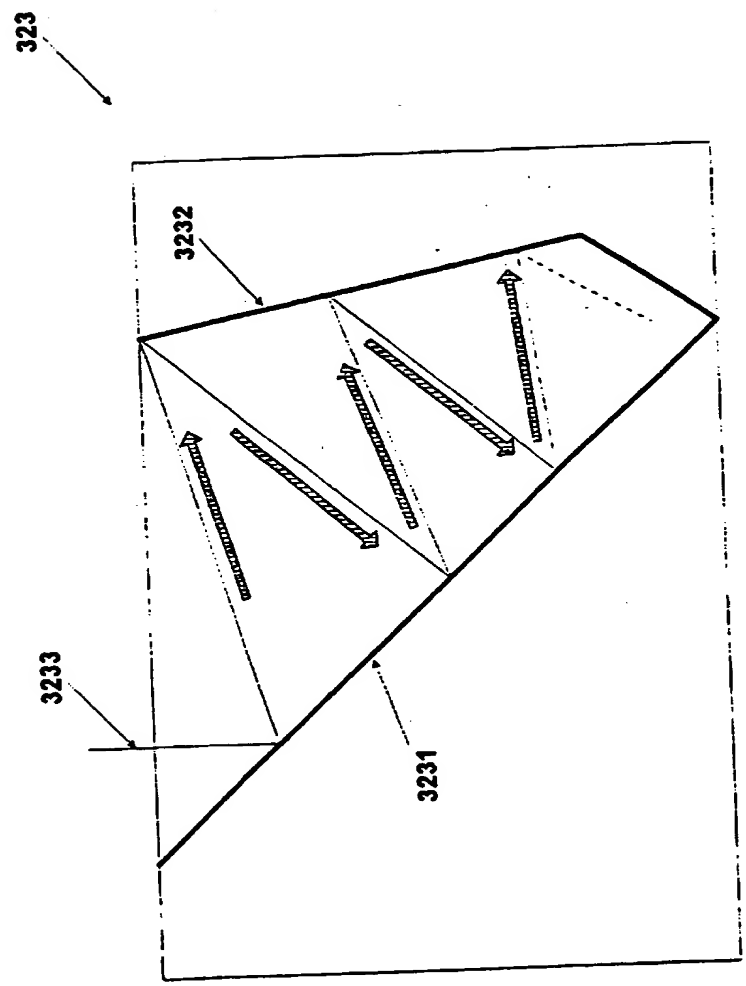


FIGURE 10

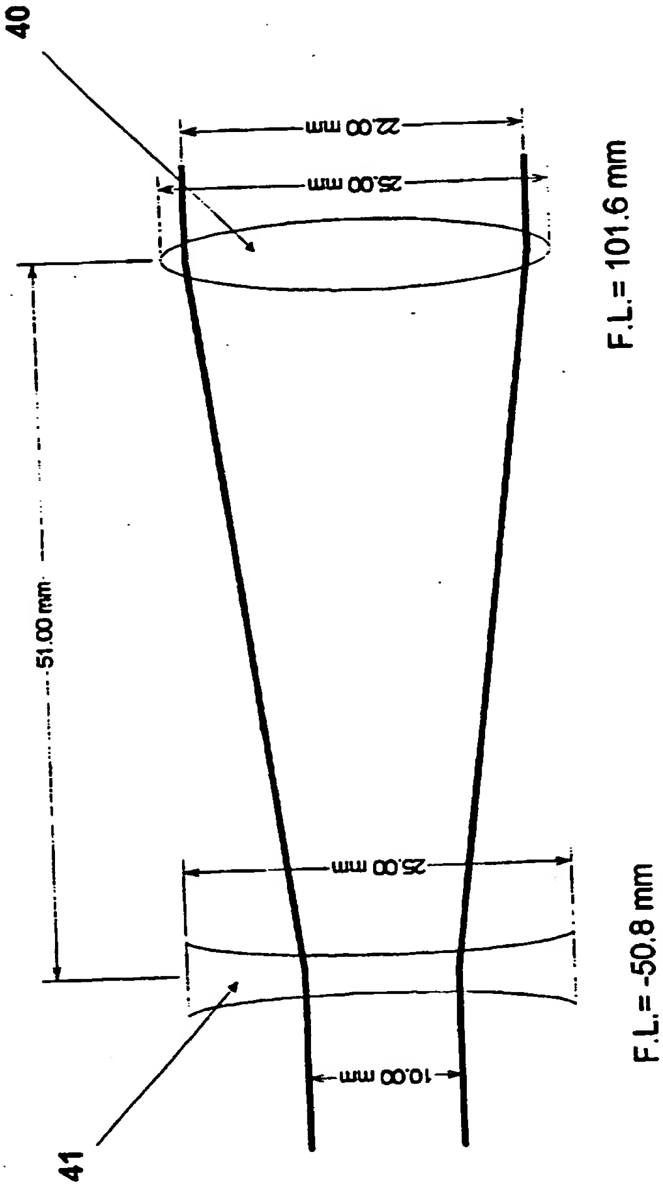


FIGURE 11

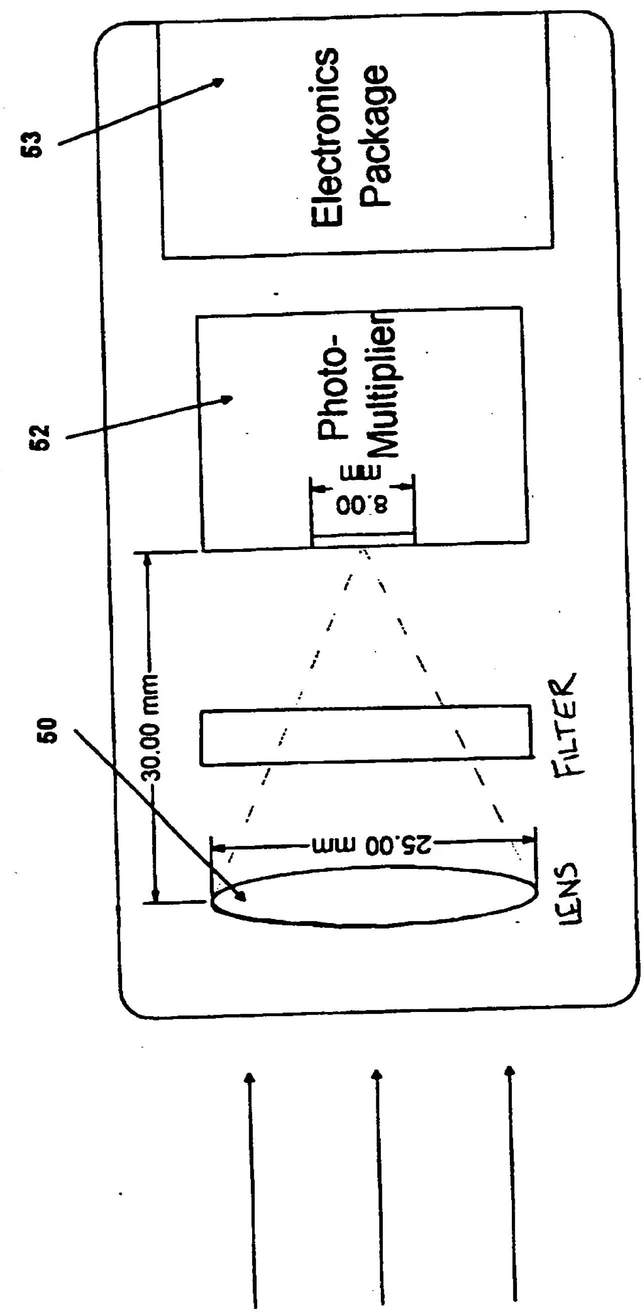

53
Electronics Package
52
Photo-Multiplier
8.00 mm
50
30.00 mm
FILTER
25.00 mm
LENS

FIGURE 12

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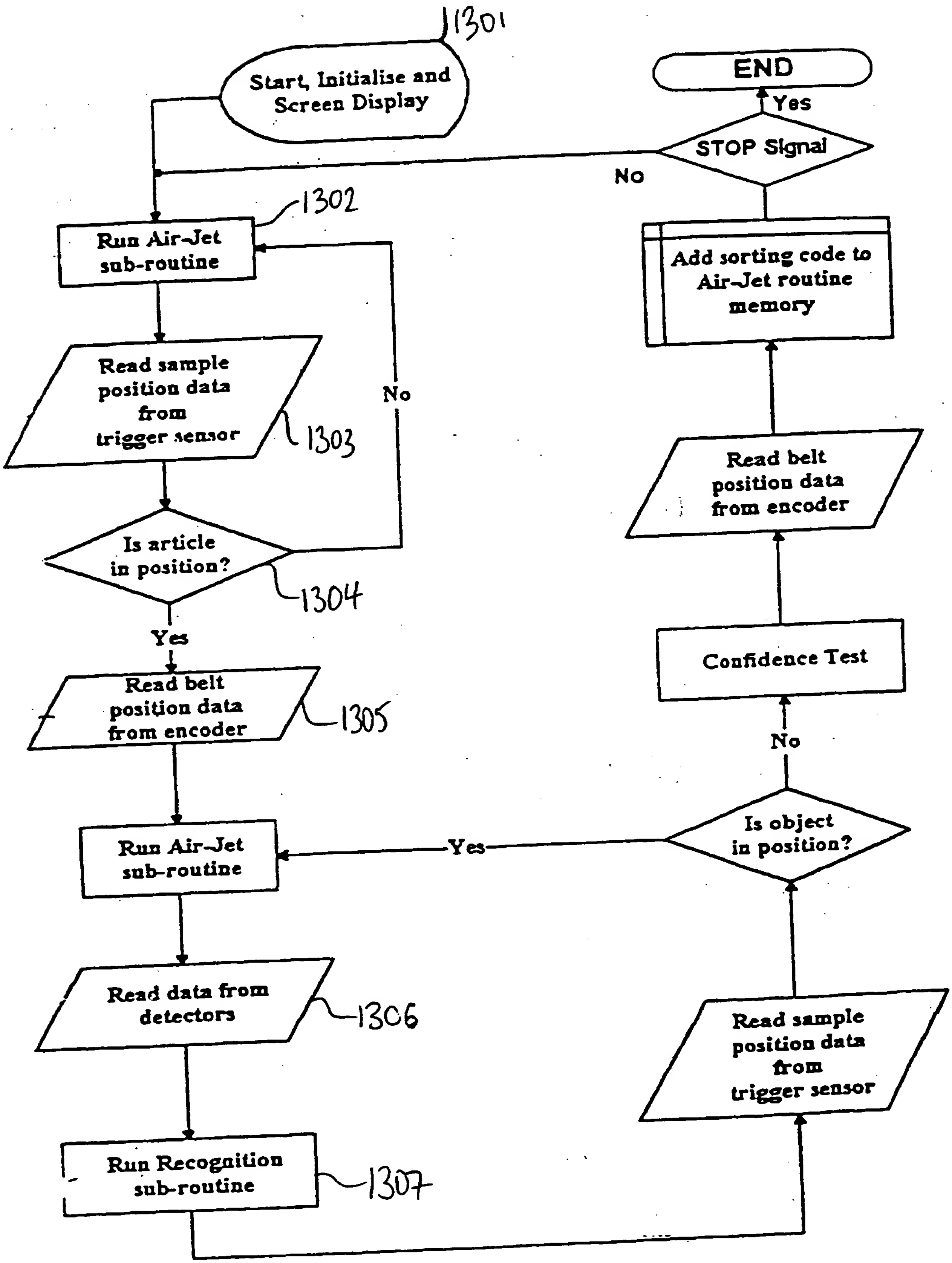

FIGURE 13

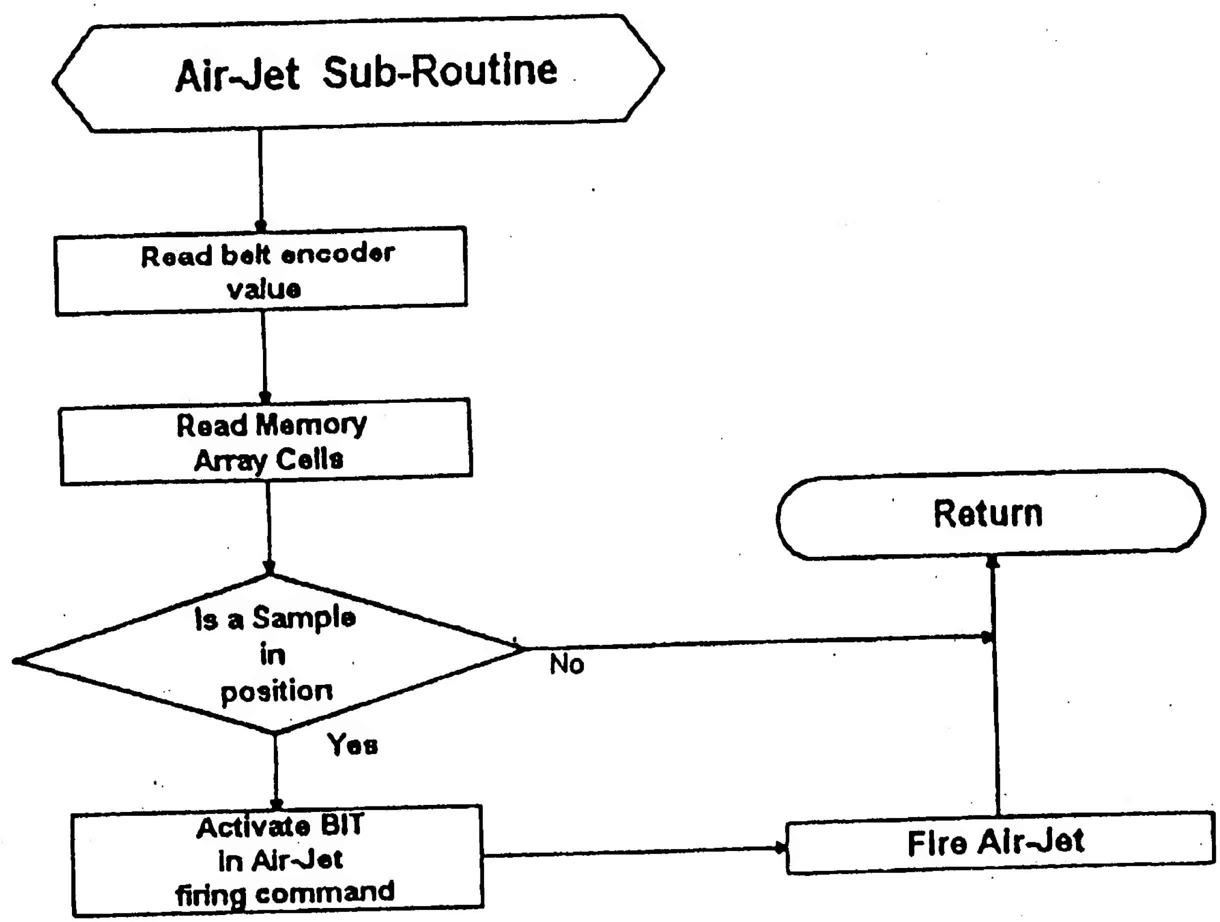
Air-Jet Sub-Routine
Read belt encoder value
Read Memory Array Cells
Is a Sample in position
No
Yes
Activate BIT in Air-Jet firing command
Fire Air-Jet
Return

FIGURE 14

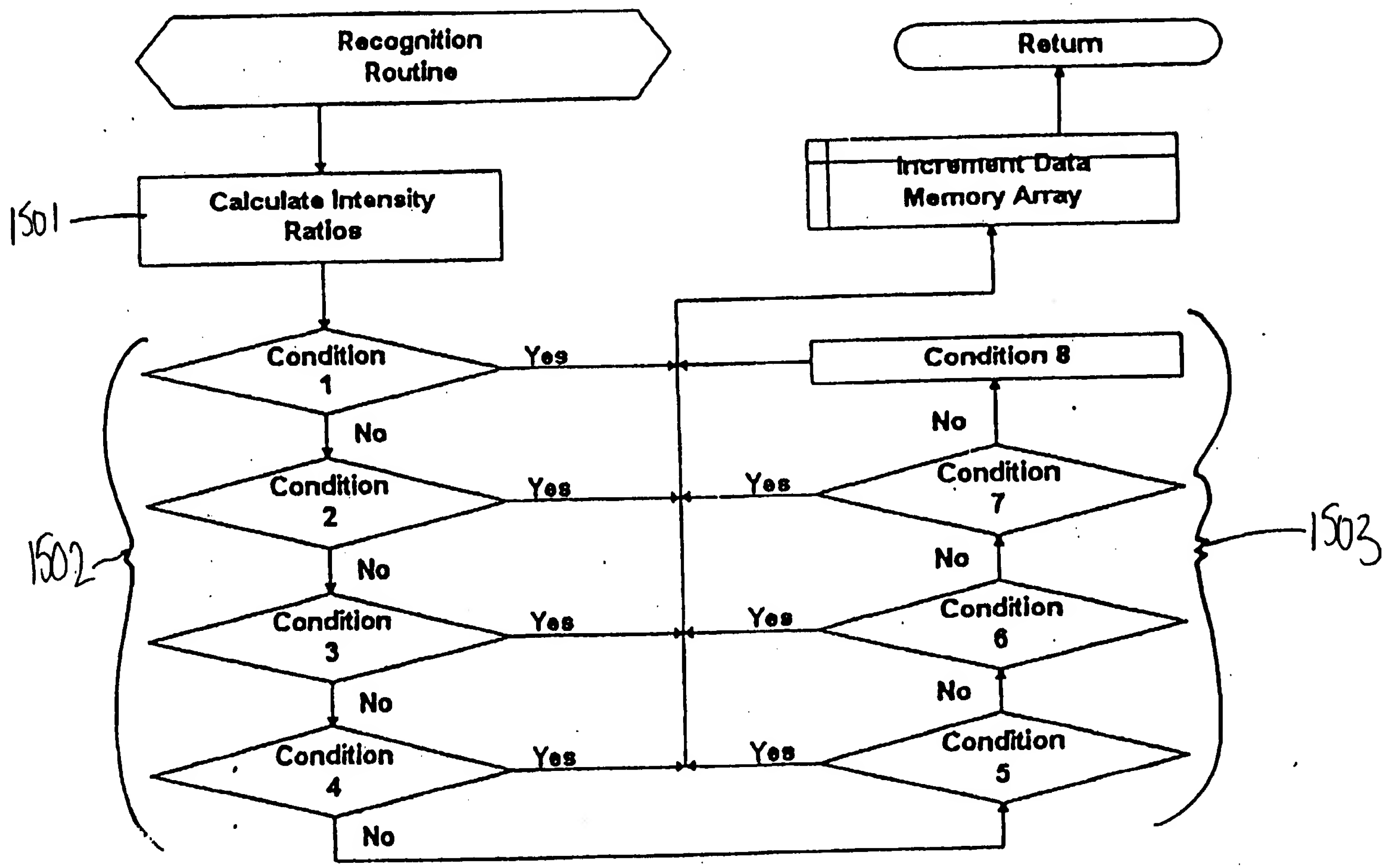
Recognition Routine
1501
Calculate Intensity Ratios
Condition 1
Condition 2
Condition 3
Condition 4
1502
Yes
No
Return
Increment Data Memory Array
Condition 8
Condition 7
Condition 6
Condition 5
1503

FIGURE 15

2330409

IDENTIFYING SUBSTANCES

The present invention relates to identifying substances, for example for sorting and recycling purposes.

The advantages of recycling materials, for example plastics, have long been known. These advantages include saving of the earth's resources and reduction of pollution. However, it is often necessary to provide a reliable way of identifying the materials to be recycled so that they can be sorted according to, for example, their chemical composition. This is particularly the case with plastics materials, where it is desirable to sort, for example, polyvinylchloride (PVC) from polyethylene (PE).

Various methods exist for sorting of plastics materials, the most basic of which is manual sorting. However, this is expensive and subject to errors induced by operator fatigue. A density difference method is cheap and reliable but is only applicable for sorting polyolefins and polyethylene or polypropylene sorting is not possible.

An electrostatic method is cheap but it depends upon surface conditions and is not industrially tested.

It is therefore desirable to provide a system for identifying substances which is reliable cheap and versatile.

According to the present invention there is provided a system for identifying a substance, the system comprising:

an ultraviolet light source for illuminating a material with ultraviolet light;

a detector for detecting fluorescence from materials illuminated with ultraviolet light;

data storage means for storing image data relating to the intensity of such detected fluorescence; and

processing means for processing the stored image data in order to determine how that image data relates to predetermined data indicative of the fluorescent material, and for producing control signals in dependence upon that relationship.

The substances to be identified can be dye tags which are impregnated into objects, the dye tags giving out predetermined fluorescence characteristics. Alternatively, the fluorescence characteristics of the object's material itself can be used to identify the object.

According to another aspect of the present invention, there is provided a filter assembly for producing a filtered output light beam, the assembly comprising a plurality of mirrors, which are arranged such that light input to the assembly is reflected between the mirrors, the mirrors having predetermined reflection characteristics which allow a portion of the light incident thereon to pass through the mirror.

Preferably, the mirrors are held on a circular frame, so that the output light beam can be rotated with respect to the input light beam.

For a better understanding of the invention, and to show how the same may be carried into effect, reference will now be made, by way of example, to the accompanying drawings, in which:-

Figure 1 shows an overall system view of a sensor system embodying the present invention;

Figure 2 shows a schematic view of an identification unit used in the system of Figure 1;

Figure 3 shows a schematic view of a detector unit used in the system of Figure 1;

Figure 4 shows a schematic view of a light source and filter assembly used in the system of Figure 1;

Figure 5 shows a cut-away view of the light source used in Figure 4;

Figure 6 shows an output characteristic of the light source of Figures 4 and 5;

Figure 7 shows a filter assembly used in the system of Figures 4 and 5;

Figure 8 shows the light characteristic output of a part of the filter assembly of Figure 7;

Figure 9 shows the overall filtered light output of the filter assembly of Figure 7;

Figure 10 shows schematically a component used in the filter assembly of Figure 8;

Figure 11 shows an output arrangement from the filter assembly of Figure 7;

Figure 12 shows a schematic diagram of a detector used in the system of Figure 1; and

Figures 13 to 15 show a flow chart of a method embodying the invention.

Figure 1 illustrates a polymer identification system embodying the present invention.

The system includes an identification unit 24 which is shown in more detail in Figure 2. An arc lamp ultraviolet source 241 is rigidly fixed to the top of a rack unit which slides into a main enclosure. The rack unit also holds an electronics module 242, a source filter 243, and a low voltage power supply 244. The arc lamp power supply 243 is mounted under the rack thereby completing a neat self-contained package. There remains sufficient space for an industrialised computer which can be dedicated to the operation of the complete system acting as an autonomous turn-key control. A detector and telescope assembly 246 is located on the identification unit.

Figure 3 illustrates a detector and telescope assembly 246 and shows the positioning of the optical and sensing devices which project from the enclosure allowing the ultraviolet beam of light to illuminate samples and the emitted fluorescent radiation to be collected and analysed.

Various ultraviolet light sources can be utilised for the identification system, since a UV source produces the best fluorescent identification signal in the visible part of the spectrum, where available detectors are at their most efficient.

Both lasers and conventional light sources including Quartz-Tungsten-Halogen lamps, gas discharge tubes and gas-filled arc lamps could be used.

Arc discharge lamps are particularly suitable for use in an embodiment of the invention, since such devices have a desired high level of ultraviolet

emission which enables sufficient levels of fluorescence to be generated in the plastics tag material.

An arc lamp 30 is shown in Figure 4 and is mounted on a support post 301 and a mounting adaptor 302. A collimating lens 31 collimates the output from the lamp 30 and introduces it into a filter assembly 32. The filtered light is output at 324.

One particular UV light source is illustrated in Figure 5 and has a modular lamp housing which uses high collection angle ellipsoidal reflectors. This fanless housing is essentially free of on-board sources of vibration. It is ideally fitted with water cooling systems for both the reflector and the lamp terminals when using lamps of power greater than 100 watts.

The spectral output of such a lamp is shown in Figure 6.

As has been mentioned above, the arc lamp emission is collected by an ellipsoidal reflector with the arc at one focus, a shown in Figure 5. The mirrored surface covers about one quarter of the locus of the ellipse and the reflected light is concentrated at the second focus. The arc lamp enclosure in this system has an aperture of F#2, giving a focal length external to the output window of 4 inches (101.6 mm). This allows the construction of a convenient, compact source filter and telescope assembly. Other elliptical configurations are available (i.e. F#3.7 and F#4.4).

Referring to Figure 4, the next stage of optical processing involves producing a beam of UV energy, as parallel as possible, from the converging wide spectral band output of the arc lamp. This can be readily achieved by directing the light through a collimating lens 31 and then into a filter assembly 32 which includes dichroic mirrors 321.

The light can be adequately collimated using a single plano-concave lens 31. The ensuing beam shows divergence of visible light outside the required band, but as will be shown below, this can be eliminated by the filtering assembly 32. A fused silica lens is particularly suitable for this collimating lens.

A suitable filter assembly is shown in Figure 7, and the mounting of the lens can be clearly seen. The length of the source support collar is preferably

machined to high tolerance for correct location.

To enable a desirably pure light output, in the band of 310 to 370 nm, the dichroic mirrors 321a... 321e are highly reflective in a band covering the 312 nm and 365 nm, peak outputs of the mercury arc lamp and are highly transmissive outside this region. Multi-layered coatings on optically flat substrates, 25.4 mm in diameter, are preferable and form effective highly selective dichroic mirrors, as illustrated in Figures 7, 8 and 9.

For horizontal illumination of the passing polymer targets the beam needed to be turned by 90 degrees. Five mirrors 321a to 321e are used in series, each with a nine degree angle of incidence to produce such a 90° turn.

As a result of the filtering process, the excitation band is reduced by between only 1% and 5%, while the radiation outside the reflection band is reduced by 10^4 to 10^6 as illustrated in Fig. 9.

An aluminium alloy ring 322 supports the mirrors 321a... 321e at the appropriate angles and the ring also holds the collimating lens 31.

The light which is transmitted through the mirrors could be the cause of unwanted noise in the subsequent detection units and also contains harmful UV energy. Therefore a light absorbing assembly 323 is preferably used to alleviate the problem.

Since the vast majority of rejected energy is passed through the first mirror 321a, the light absorbing assembly 323 is placed behind the first mirror 321a.

The light absorbing assembly 323 is shown in more detail in Fig. 10 and comprises of two neutral density filters 3231, 3232 mounted such that a large number of reflections are caused within the assembly 323 cavity. These filters have an absorbence of about 10^4 in the visible and infra-red spectral regions and, because at least 5 reflections are produced, reduce the transmitted energy to negligible levels.

A further neutral density light absorbing assembly of the same material can be placed behind the second dichroic mirror 321b in the main sequence.

In order to prevent divergence and to achieve a smaller spot size, a

reverse telescope is provided to tailor the beam before illuminating the target, as shown in Fig. 11. Using a suitable pair of fused silica lenses 40, 41 a diameter of 10 mm can be achieved. The same anti-reflection coating as that used on the collimating lens is preferably used on all surfaces.

The target objects, which are preferably made of various types of dye-tagged plastics, or are of self-fluorescing material, are illuminated by the beam of ultraviolet light and traverse the field of view at a fairly rapid rate. The objects vary in shape and size, and therefore the illuminating spot of light generates fluorescent emission at different distances from the fixed detector position. It is thus desirable to provide a detector which renders the system insensitive to object distance changes. Figure 12 illustrates schematically such a system.

By taking account of the mechanical and physical restraints in an industrial situation, a fair assumption is that the average distance from target to collecting lenses is 300 mm. Single element collecting lenses (50) are used and have focal length 30 mm.

Interference filters 51 are used to distinguish the various spectra emitted from the samples because of their versatility, size, narrow bandwidth, throughput efficiency, ease of availability, and cost. Possible alternatives are a scanning monochromator with a single detector using either a prism or grating as the dispersive element, or a fixed prism or grating and multiple detectors.

The first alternative is not ideal since it tends to slow down the acquisition process. The second option is also not ideal since the dispersion can be too limited.

Interference filters select a narrow range of wavelengths with high transmission efficiency through a complex process of constructive and destructive interference.

A photomultiplier is preferably used for detection of the light beam in the region of 400 to 600 nm, and with a light intensity generating a signal of 1 volt across a load of 0.5MΩ the incident power must be 0.25 nW.

A photosensor 27 (Figure 1) is provided in order to detect the presence

of a target. Only then does the computer receive data for processing from the identification detectors via an A to D converter. This 'trigger' device 27 is preferably a photo-diode placed in line with the source beam on the far side of the targets from the detector. The diode aperture is preferably fitted with a fluorescent screen which converts the ultraviolet energy from the arc lamp to a colour more suitable to the diode's spectral sensitivity. The diode encapsulation also contains circuitry which performs a 'Schmitt triggering' action such that, as soon as the light energy reaches a specified level, the output switches from a 'low' value to a 'high' value. The reverse reduction in light energy switches the output at a slightly higher transition point. The technique reduces the chances of rapid noise signals causing false triggering.

The photo-sensor modules and trigger sensor are preferably designed as self-contained devices.

The signals generated by the photomultipliers and trigger photodiode must be processed prior to being received by a computer.

The photomultipliers are controlled by an internally stabilised voltage source the level of which is set by an adjustable potentiometer on a control panel.

Four PMT's are used in the present embodiment, and so four channels of electronics are needed.

The signals generated in the electronics package described above are composed of continuously varying voltages proportional to the light intensity.

In order that fast, accurate calculations may be performed, these voltages have ideally to be converted into a digital format for input to a computer. An analogue to digital (A to D) converter is provided in order to produce image data for use by the computer.

One of the most important criteria to be considered is the resolution of the digital data. Normally DC voltages are converted using binary devices where the maximum voltage likely to occur is divided by a factor of two raised to some high power. Converters come in various levels, i.e. 2^n, commonly termed 'n' bit devices.

For example, a conversion level of 2^{10}, (10 bit converter) and full scale amplitude of 2.5 volts enables a resolution of 2.5/1024 or 2.4 mV to be achieved.

A 14 bit converter enables the resolution to increase to 150μV. This increase however comes at the expense of speed which is the second criterion when choosing a device.

The rate at which a conversion is made depends on the pulse rate and the signal level. For signals which do not vary much, the time taken will not vary much.

This description covers a large range of fairly simple devices that are available. There are also much more sophisticated A to D converters called 'Flash' devices. These are much faster in operation but at greater cost. However, since ultra-high data rates are not needed for this application, flash devices are not required, but could of course be utilised nevertheless.

The digital signal processing can be performed in hardware, firmware, software or any combination of these.

Figures 13 to 15 show flow charts of the steps in a method implementing the present invention.

Comparison data is stored in a memory array until after the target has passed the illuminating beam. There is then sufficient time for the individual sets of data comparisons to be made.

Referring to Figure 13, the process is started (1301) and a screen display reset. The air-jet routine is run (1302) in order to determine the current conveyor position. Data is then read from a position sensor (the trigger sensor) in order to ascertain whether an article is in position. If no article is yet in position, the trigger sensor is continuously monitored until an article is detected.

When an article is shown to be in position from the position sensor data, and hence producing fluorescent light in reaction to the UV light source emission data is read (1306) from the optical detectors after conveyor belt position information is obtained (1305). This intensity data is stored in an array and data is continued to be read from the detectors while the object is in

position. As soon as the object moves out of position a confidence test of the stored data sets starts (1307).

Referring to Figure 15, the ratios of the different detected light levels are calculated and then coupled with stored data relating to expected outputs from the detectors. (Steps 1501, 1502, 1503). When a comparison determines that the detected values equal the stored data, data is stored which indicates this match. This data can then be used by the remaining parts of this system to sort the objects. A confidence level sets the level at which the count can be accurately considered to relate to a single material. This level is compared with the stored data to enable the system to make a final decision regarding the type of material detected in the targets.

The complete identification assembly is compact and easily installed. Overall maintenance requirements should be low. The optics can be sealed against industrial pollution with the possibility of regular automatic cleaning under a computerised supervisor. The only delicate region may be the arc lamp replacement but it is envisaged that this can be a self-aligning cartridge simply removed for a new one, the old one returned to the supplier for refurbishment.

The electronics are quite rugged and can be industrialised and, if necessary, tropicalised. The power requirements are low and compatible with mains supplies world-wide.

A conveyor assembly 201, 202 can be provided for transporting targets from a supply hopper 23, past the identification unit 24, and on to the separation point.

The conveyor system belts are preferably made of a rubber composite material chosen for its high friction coefficient especially where light objects are to be moved at fairly high speed. In this design, the belt associated with the supply hopper is 100 mm wide and the second belt is 200 mm wide. The sections of the unit are driven separately by variable speed motors allowing belt speeds from 2 to 20 metres per minute. If bunching occurs on the supply belt, this separation enables the samples to be spread out by simply running the second belt faster than the first.

One way of separating articles is to use an air jet system. Referring once more to Figure 1, separation of the samples 22 after identification is performed pneumatically with compressed air jets. The jets 251 are mounted in the side walls of the conveyor 202 and are activated via high speed electric valves in accordance with the control signals from the computer. The samples are thereby blown into individual respective collection bins 252.

The collection bins 252 are located towards the end of the second belt and are designed to each have the capacity for one quarter of the hopper contents in this design. They have deflectors over their upper apertures to ensure that the air driven samples fall dependably into the cavity. They may also have closable ports at the bottom for removal of the separated samples. A further bin 253 is placed at the end of the conveyor 202 to receive untagged or unidentified objects 22.

Industrial systems will probably sort targets which vary in length between 10 and 500 mm long. To enable 10 targets per second to be analysed a belt speed of 6 metres per second will be involved. If the targets are, on average, 300 mm long the scanner will 'see' them for 50 msec.

A shaft encoder driven by the second conveyor motor, so that the pneumatic vales are operated at the correct time to blow the targets off the conveyor into appropriate collecting bins.

There are many sources of waste plastic material which are, at present, disposed of inefficiently. For example, the waste products of industrial processes, and domestic waste. It has been suggested that the producers of raw polymer stock are interested in the unused material but would not enjoy its contamination with material from other producers. Tagging and sorting in this field is a viable solution and the equipment embodying the present invention can therefore provide the means for such sorting.

Another use for such a system is for the dedicated disposal of manufactured goods such as polyurethane foam for seating and bedding and the many polymer parts in vehicles and domestic appliances.

The fundamental detection equipment herein developed may also be

tailored for use in the quality control of many self-fluorescing products. The food and drugs industries use numerous ingredients which provide characteristic signatures. These can serve to be identifiers of quality and concentration. Certain waste products, such as water and industrial solvents, may also be scanned for pollutants using the method outlined above.

CLAIMS

1. A method for identifying a substance comprising:

illuminating a substance with ultraviolet light;

detecting fluorescence from the substance illuminated with ultraviolet light;

storing image data relating to the intensity of such detected fluorescence; and

comparing the stored image data with predetermined image data and producing control signals in dependence upon that comparison.

2. A method as claimed in claim 1, wherein the substance to be identified is a tracer material impregnated into an object.

3. A method as claimed in claim 2, wherein a plurality of tracer materials are impregnated into the object.

4. A method as claimed in claim 3, wherein each such tracer material produces an individual fluorescent signal, the stored image data and the predetermined image data defining identification data sets indicative of respective combinations of such tracer materials.

5. Apparatus for identifying a substance comprising:

a light source for illuminating material with ultraviolet light;

at least one detector for detecting fluorescence from the materials illuminated with ultraviolet light;

data storage means for storing image data relating to the intensity of such detected fluorescence; and

processing means for processing the stored image data in order to determine how that image data relates to predetermined data indicative of the fluorescent material, and for producing control signals in dependence upon that relationship.

6. Apparatus as claimed in claim 5, wherein the substance to be identified is a tracer material impregnated into an object.

7. Apparatus as claimed in claim 6, wherein the object is impregnated with a plurality of tracer materials, each of which produces an

individual fluorescent signal, the processing means storing the predetermined data which relates to predetermined combinations of such dye tag materials, the detected fluorescence being indicative of the combination in an object.

8. Apparatus as claimed in claim 6 or 7, comprising sorting means responsive to the control signals for sorting objects from a plurality of objects, the sorted objects producing a predetermined fluorescence signal.

9. Apparatus as claimed in claim 8, wherein the sorting means include a conveyor belt for transporting objects therealong, and a plurality of air jets operable to blow objects from the conveyor belt.

10. A filter assembly for producing a filtered output light beam, the assembly comprising a plurality of mirrors, which are arranged such that light input to the assembly is reflected between the mirrors, the mirrors having predetermined spectral reflection characteristics which allow a selected portion of the light incident thereon to pass through the mirror.

11. An assembly as claimed in claim 4, wherein the mirrors are held on a circular frame, such that an output light beam is rotated with respect to the input light beam.

12. A method for identifying a material substantially as hereinbefore described with reference to the accompanying drawings.

13. A system for identifying a material substantially as hereinbefore described with reference to, and as shown in, the accompanying drawings.

The Patent Office

14

Application No: GB 9722032.1
Claims searched: 1-9

Examiner: Andrew Bartlett
Date of search: 22 July 1998

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.P): G1A (AMK, AMG, AMHL); B6A (ATC, AK, AL)

Int Cl (Ed.6): B07C 5/34 & 5/342; B29B 17/00 & 17/02; G01N 21/63 & 64;

Other: ONLINE:- WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage			Relevant to claims
X,Y	GB 2190996 A	(WEST)	See whole document	1,2,5,6 at least
X,Y	EP 0466474 A1	(DOWTY SEALS)	See whole document	1,2,5,6
X,Y	US 5329127	(BECKER ET AL)	See whole document	1-9
X,Y	US 5201921	(LUTTERMANN ET AL)	See whole document	1-9
X,Y	US 4567370	(FALLS)	See col 3 lines 39-53 in particular	1-9
Y	WO 94/11126	(FORD)	See claim 1 in particular	1-9

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.